CORROSION-RESISTANT STEEL FIBER PRODUCED BY THE MELT-EXTRACTION METHOD AND ITS USE IN REFRACTORIES

Van I-Kho and Lyu Ven-Nen

UDC 669-494:669.531.262

Corrosion-resistant steel fiber produced by the method of rapid hardening of a melt on a rotating disk is a new type of microcrystalline material. The reinforcement of refractory concrete is one of the important fields of its use. The introduction of these fibers in refractories improves thermal stability, resistance to mechanical impact, and the strength characteristics of furnace linings and other articles. Reinforcement with corrosion-resistant steel fibers extends the service life of refractories, as a result of which the productivity of various furnaces and apparatus is enhanced. This paper cites examples of the use and properties of refractories reinforced with steel fiber.

Articles produced by different methods where the melt is subjected to rapid cooling exhibit unique properties and have different ranges of application. It should be noted that only two methods for rapid hardening of the melt can be used on industrial scales. These include the "spinning" method — for the production of amorphous alloys — and the method of extracting fibers from the melt — for the manufacture of metallic fibers.

At the present time, corrosion-resistant steel fiber is widely used in developed countries. Approximately 2000 and 500 tons are produced annually in the United States and England, respectively [1, 2]. More than 200 tons were produced in China in 1991.

Production of Fibers from Melt. A schematic diagram showing the production of fibers by the melt-extraction method is shown in Fig. 1. After the metal has been melted-down, a rotating disk is lowered to the surface of the melt, and the edge of the disk is immersed to a certain depth in the melt. Rotating together with the disk, a solidified layer of metal emerges from the melt, hardens, and is separated from the disk as a result of shrinkage and centrifugal forces, and is then discharged into a collector. Since radial slots are located a given distance apart on the edge of the disk, the resultant fiber possesses a determined length. On an industrial unit, roller brushes are mounted additionally above the disk to clean its surface. A protective atmosphere is frequently employed to eliminate oxidation of the melt.

According to Vasil'ev and Mitin [3], the production of steel fibers consists of three stages: I — solidification of metal on the edge of the disk, which is immersed in the melt; II — cooling of the layer of metal that has partially or completely solidified on the disk after a segment has emerged from the melt; and, III — final cool-down of the metal that has separated from the disk. The cooling rate of the metal in stages I and II is 2-3 orders higher than that in stage III, since heat transfer in the latter is accomplished by convection, and not by heat conduction.

To generate higher solidification and cooling rates of the fibers, it is necessary to select a disk material with the highest heat conduction. In the general case, where the fiber is on the edge of the disk, the temperature gradient between their surfaces is approximately 500°C. The temperature of the fiber approaches 1000°C at the point where it meets the disk. In this connection, a cooled collector is frequently installed in advance of the disk for a further increase in cooling rate. It should be noted that for the majority of alloys, the structure of the material and the distribution of secondary-phase particles vary in the process of cooling from 1000°C to room temperature. Considering the importance of phase stability for rapid solidification of the fibers of different alloys, it is necessary to select their composition.

As was noted above, solidification of fibers occurs in the first stage; in this case, the thickness of the fiber $h$ is defined as
TABLE 1

<table>
<thead>
<tr>
<th>Grade of fiber</th>
<th>Element content, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ni</td>
</tr>
<tr>
<td>StA (330)</td>
<td>35</td>
</tr>
<tr>
<td>StB (310)</td>
<td>20</td>
</tr>
<tr>
<td>StC (304)</td>
<td>10</td>
</tr>
<tr>
<td>StD (446)</td>
<td>—</td>
</tr>
<tr>
<td>StE (430)</td>
<td>—</td>
</tr>
</tbody>
</table>

Fig. 1. Diagram showing production of steel fibers by melt-extraction method: 1) disk; 2) melt; 3) crucible; 4) fiber.

\[ h = h_1 + h_2 \]

where \( h_1 \) is the thickness of the solidified layer, and \( h_2 \) is the thickness of the viscous shear layer in the melt.

From Antony and Cline [4],

\[ h_1 = \left( a \frac{\Delta T}{A_H} \right) (R \theta / \rho) \]

\[ h_2 = \left( \frac{vQ_pR}{\rho_s \nu} \right)^{1/2} \]

where \( a \) is the heat-transfer coefficient, \( \Delta T \) is the temperature difference on the interface, \( A_H \) is the heat liberated by a unit of volume during its solidification and cooling, \( R \) is the radius of the disk, \( \theta \) is the angle of contact between the disk and melt, \( \nu \) is the linear velocity on the effective edge of the disk, \( \nu \) is the kinematic viscosity of the metal, and \( \rho_m \) and \( \rho_s \) are the densities of the melt and solidified material, respectively.

The experiments indicated that the material of the disk, its turn rate and rate of descent, the edge profile, and the viscosity of the melt exert an influence on fiber formation. To produce the required dimensions and good fiber quality, it is necessary to optimize the conditions under which fibers are produced from each prescribed alloy.

The chemical composition of the corrosion-resistant steel fibers is present in Table 1.

Reinforcement of Refractory with Corrosion-Resistant Fibers. At the present time, refractory concrete is coming into increasingly widespread use in various furnaces and units that operate at high temperatures. Its basic disadvantage is its brittleness as the temperature of the lining changes, especially if the articles formed from the refractory concrete operate under conditions where the temperature differs on the inside and outside of the unit. It is known that the bonding strength of the refractory is governed by hydration hardening at low temperatures, and by ceramic bonding at high temperatures. A sharp reduction in hydration hardening is observed in the 700-900°C interval in which conditions for ceramic bonding have not as yet been met; the refractory, therefore, frequently fails in service under these conditions.

It follows from the theory of fiber reinforcement that if a certain amount of corrosion-resistant steel fibers is introduced to the refractory, the stress distribution in the latter will vary significantly with an abrupt temperature change. The fibers play the role of crack "traps" in this case. In addition to coarse cracks, fine and disperse cracks are formed in the refractory [5, 6].